Assimilating cloudy and rainy microwave observations from SAPHIR on-board Megha-Tropiques within the ARPEGE global model

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Introduction

Within the 4D-Var ARPEGE global data assimilation system in operations at Météo-France, only clear-sky microwave observations are presently used. A new framework is currently under investigation to assimilate as well microwave observations in cloudy and rainy areas. The method is called "1D-Bay+4D-Var" and corresponds to a two-step process: (i) a Bayesian inversion algorithm to retrieve profiles of humidity from the microwave radiances, (ii) the 4D-Var assimilation of these retrieved profiles. The 1D-Bay+4D-Var method is an alternative to both 1D-Var+4D-Var and direct all-sky assimilation; it has been successfully used in operations for the assimilation of ground radar reflectivities within the AROME mesoscale model since 2010 (Wattrelot et al. 2014). It was also experimented for SAPHIR observations and the ALADIN regional model over the Indian Ocean (Guerbette et al., 2016). The following poster details the current status of this development.

Main characteristics of the NWP system used in this study:

→ Research version of the ARPEGE global prediction model including a convection scheme with prognostic hydrometeors PCMT (Guérémy and Piriou, 2017)

→ Spectral resolution : T1200 (~7 km over Europe)

→ Vertical resolution : 105 levels

→ Model version : cy42op2

→ 4D-Var Data Assimilation System using 6h windows and flow dependent Background errors

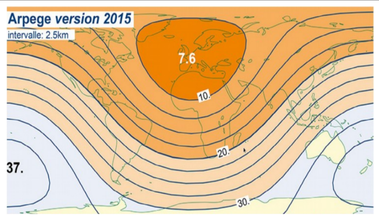

Figure1: Horizontal resolution of tilted/stretched grid of the ARPEGE model

Main characteristics of the Megha-Tropiques/SAPHIR observing system:

→ Megha-Tropiques is an Indo-French satellite in low inclination orbit (20°) providing an enhanced sampling of Tropical regions

→ Megha-Tropiques carries three instruments including the SAPHIR cross-track microwave humidity sounder

→ SAPHIR observes the atmosphere with 6 channels around the 183,31GHz water vapor absorption band

→ SAPHIR horizontal resolution at nadir: 10km

→ Data available since the October 12th, 2011

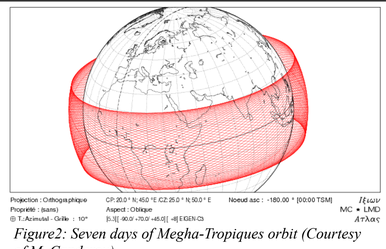

Figure2: Seven days of Megha-Tropiques orbit (Courtesy of M. Capderou)

➢ The Bayesian framework developed for SAPHIR observations retrieves relative humidity profiles as a weighted combination of profiles from a training database:

$$x_{obs} = \frac{\sum_{j=1}^{80} x_j w_j}{\sum_{j=1}^{80} w_j}$$

$w_j = \exp(-J_o)$ and J_o the cost function:

$$J_o(x_j) = \frac{1}{2}\sum_{i=1}^{6}\left(\frac{T^i_{model}(x_j) - T^i_{obs}}{\sigma_o}\right)^2$$

➢ The used database is made of profiles from the first guess in the vicinity of each observation (~200 km neighborhood)

➢ Each weight is computed taking into account the distance between the observed brightness temperatures, the simulated brightness temperatures from the database and inversion errors.

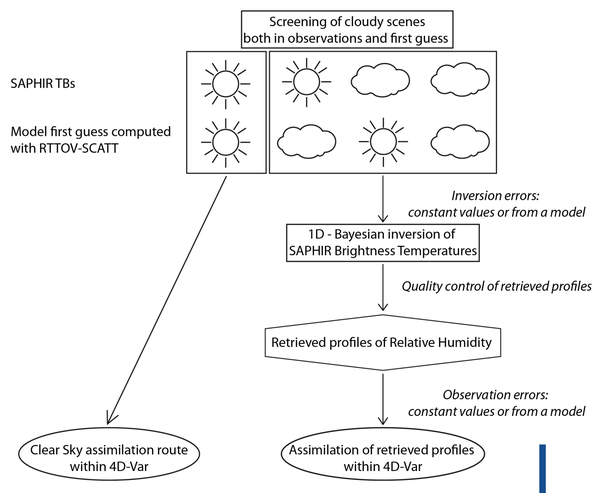

Figure 3: Flowchart of the assimilation framework

Brightness temperature Inversion errors within Bayesian retrieval

➢ The inversion error within the inversion can either be prescribed to a fixed value (e.g. 1K for an accurate retrieval) or be prescribed with a model like defined below

➢ A simple model was built up based on an ensemble of radiative transfer simulations using multiple radiative properties for hydrometeors (Fig 4)

➢ This model prescribes larger errors for the strongest scattering scenes and allows to retrieve information within deep convective cores (Fig5)

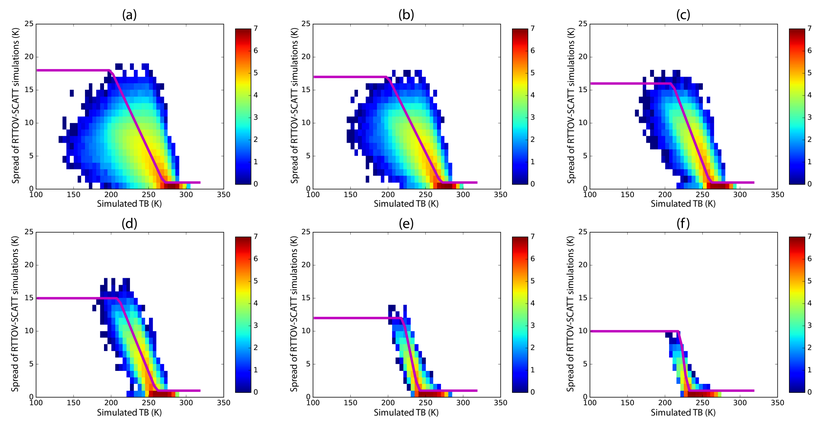

Figure 4: Scatter plots of estimated radiative forward simulation uncertainties for each of the six SAPHIR channels (a: channel 6, b: channel 5, c: channel 4, d: channel 3, e: channel 2, f: channel 1). The spread of a group of four simulations with 3,4,5,6 bullet rosettes and the sector snowflake particle shapes is plotted against each of the four forward simulations. The number of samples, corresponding to one-month of SAPHIR observations in January 2017, is represented in colour with a log10 scale. The purple straight lines correspond to the empirical models fitting the modes of the distributions.

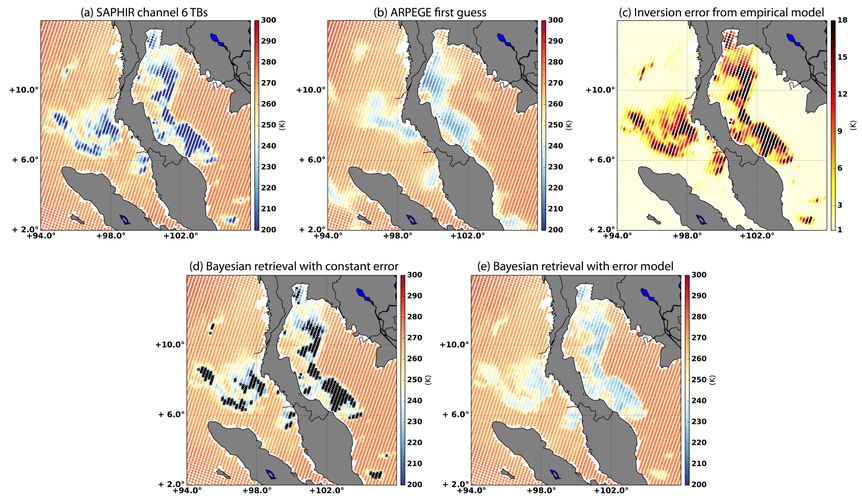

Figure 5: (a) Observations from SAPHIR channel 6 on January 8th, 2017 at 00h00 UTC; (b) the corresponding model guess at this same time and location; (c) retrieval in the brightness temperature space, considering an inversion error of 1 K; (d) retrieval in the brightness temperature space, considering the inversion error model adapted to the observed scenes. Little black crosses represent locations where the Bayesian inversion is unsuccessful.

Relative humidity retrieval Observation error within 4D-Var

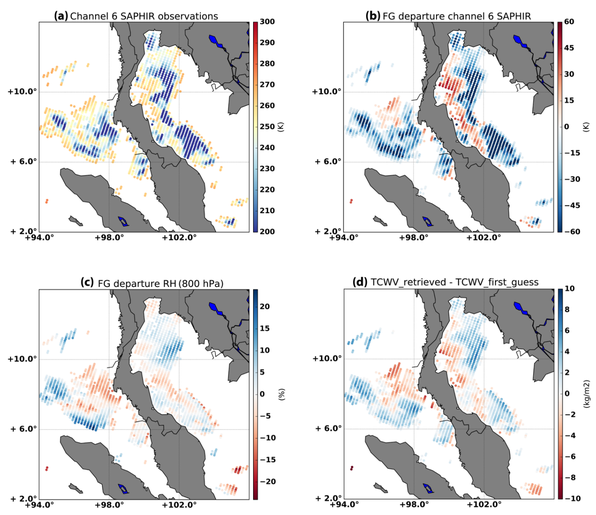

Figure 6: (a) Observations from SAPHIR channel 6 on January 8th, 2017 at 00h00 UTC which have been selected for the Bayesian framework; (b) first guess departure in brightness temperature space; (c) retrieved RH first guess departure at 800 hPa; (d) retrieved TCWV first guess departure.

➢ The observation error within 4D-Var can either be prescribed to a fixed value (e.g. 12% of relative humidity) or be prescribed as variable

➢ An error model was built up, based on similar ideas than in Geer and Bauer (2011) but adapted to the assimilation of RH estimates

➢ Predictor used: difference of TCWV between the observation and first guess

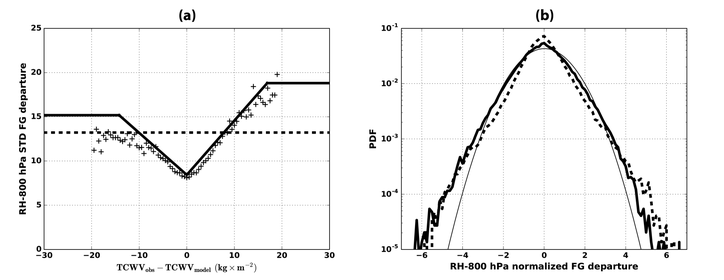

Figure 7: (a) Standard deviation of first guess departures of relative humidity at 800 hPa, categorized as function of $TCWV_{obs} - TCWV_{model}$ (crosses), empirical model (thick line), constant observation error (thick dashed line). (b) Distributions of first guess departures of relative humidity at 800 hPa, normalized with the empirical model (thick full line), normalized with a constant observation error (thick dashed line), compared to a Gaussian distribution (thin full line).

Assimilation experiments

➢ Assimilation experiments have been conducted over a 3-month period (January to March 2017) with SAPHIR rainy observations assimilated in addition to a full observing system as in operations.

➢ Impacts are found to be positive for ARPEGE short term forecasts with respect to satellite observations like SATOB data for winds, AMSU-A for temperature and MHS for humidity.

➢ Positive impacts are also found with respect to the ECMWF analysis up to a +48h range.

	Reference	INV-cst ASSIM-cst	INV-mod ASSIM-cst	INV-cst ASSIM-mod	INV-mod ASSIM-mod
Assimilated Observing system	Observing system assimilated in operations	Reference + RH at 4 levels from SAPHIR Bayesian inversion over oceans	Reference + RH at 4 levels from SAPHIR Bayesian inversion over oceans	Reference + RH at 4 levels from SAPHIR Bayesian inversion over oceans	Reference + RH at 4 levels from SAPHIR Bayesian inversion over oceans
Inversion error	/	1 K	Model	1 K	Model
Observation errors for retrieved RH	/	constants (see Table 5)	constants (see Table 5)	model (see Table 5)	Model (see Table 5)
Clear-sky route: SAPHIR data count	15 791 911	15 453 419 -2.143 %	15 453 239 -2.144 %	15 452 954 -2.146 %	15 456 554 -2.123 %
Bayesian route: retrieved RH data count	/	2 486 056 + 15.743 %	2 491 923 + 15.780 %	2 471 085 + 15.648 %	2 476 718 + 15.683 %

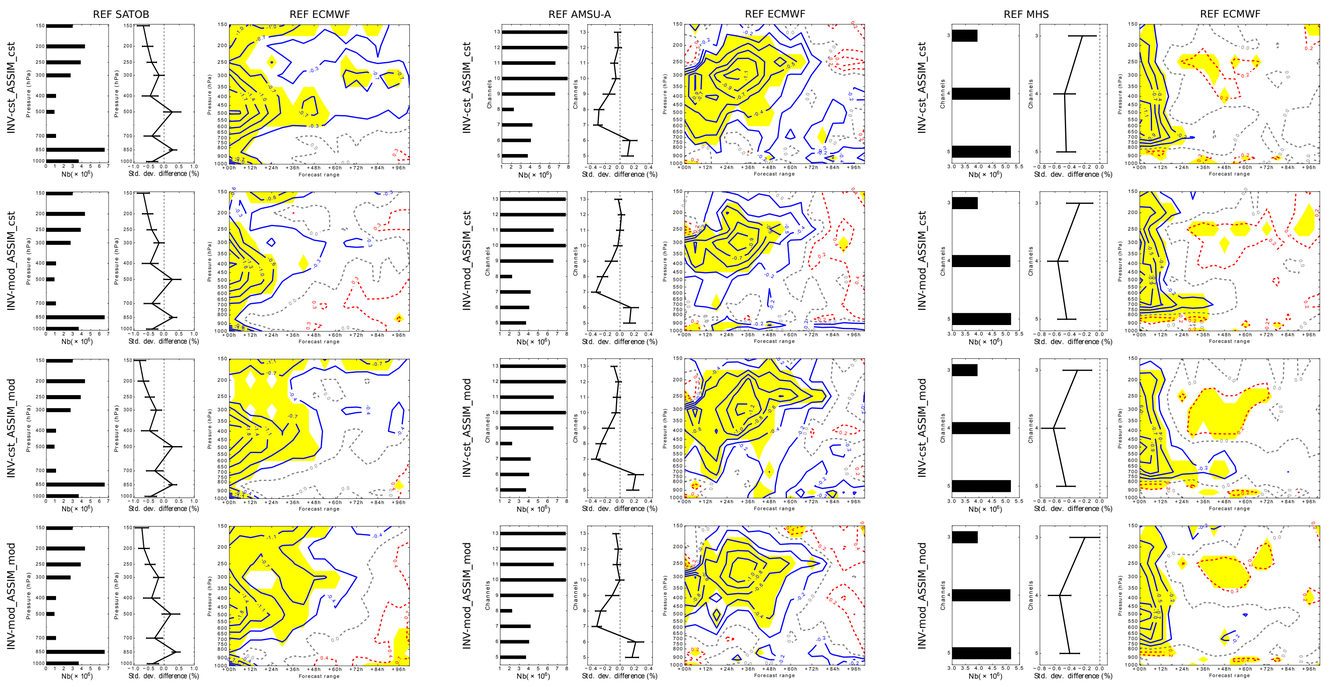

Figure 8: Relative differences (%) of standard deviation error for wind (left block), temperature (middle block) and relative humidity (right block) forecasts between the Reference and the four other assimilation experiments. Negative differences indicate a positive impact of the SAPHIR observations in clouds and precipitation. The error bars drawn on the middle column of each block of figures, correspond to confidence intervals at 95%. Yellow filled areas in the right column of each blockfigures correspond to impacts which are statistically significant at the 95% confidence level. The first row corresponds to scores for the INV-cst_ASSIM-cst experiment, the second row to scores for the INV-mod_ASSIM-cst experiment, the third row to scores for the INV-cst_ASSIM-mod, and the fourth row for the INV-mod_ASSIM-mod experiment. All these scores are computed over the whole tropical belt between 30°S and 30°N, from January 2017 to Mach 2017.

Conclusion and perspectives

➢ Longer experiments with the current framework with the objective of activating these developments into the 2019 Météo-France parallel suite

➢ Future developments: online multiple particle shapes radiative transfer simulations instead of the error model, adaptation of these developments to the other microwave imagers and sounders of the GPM constellation

Fabrice Duruisseau, Philippe Chambon, Eric Wattrelot, Marylis Barreyat, Jean-François Mahfouf. 2018. Assimilating cloudy and rainy microwave observations from SAPHIR on-board Megha-Tropiques within the ARPEGE global model. Submitted to QJRMS

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